MONTHLY WEATHER REVIEW

HERBERT H. KIMBALL, Acting Editor.
CHARLES F. BROOKS, Associate Editor.

VOL. 47, No. 1.
W. B. No. 675.

JANUARY, 1919.

CLOSED MAR. 5, 1919.
ISSUED APRIL 7, 1919.

CONTRIBUTIONS AND BIBLIOGRAPHY.

WORK OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY AT CALAMA, CHILE.

By C. G. ABBOT, D. Sc., Assistant Secretary, Smithsonian Institution.

[Dated: Washington, Feb. 17, 1919.]

Since the year 1902, the Smithsonian Astrophysical Observatory has been conducting observations to determine the solar constant of radiation. Early in the work it appeared that the solar radiation is not constant but variable in short irregular intervals of a few days or a few weeks, and later it appeared that the sun varies also in average output of radiation from year to year. The longer period variations seem to be associated with sunspot and other visible solar activities, and the shorter-period irregular fluctuations we have found to be associated with changes of distribution of brightness along the diameter of the solar image. We incline to assign the causes of these observed variations as follows:

When the sun is in great activity, as shown by sunspots, prominences, and the like, it is like poking a fire and bringing fresh coals to the surface. Thus, we look at such times on a hotter sun, and naturally we obtain greater values of the solar constant of radiation corresponding. This view is confirmed by the studies of the changes of distribution of radiation over the sun's diameter, for if the temperature of the sun were zero there would be no contrast of brightness whatever along the diameter, and the higher the temperature the greater becomes the contrast. We have found, correspondingly to this, more contrast between the brightness of the center and edges of the sun at times when the solar activity was high.

The shorter irregular fluctuations of solar radiation we have explained by changes in the transparency of the outer solar envelopes. This view is supported by the solar contrast work, for we find that high values of the solar radiation, as they fluctuate to and fro in their irregular intervals of time, correspond to low values of contrast between the center and edge of the sun.

It will be clear to the reader that if the sun's outer envelopes become more transparent, the result would be to increase the radiation at all points of the sun's disk, but the increase would be greatest at the solar limb, where the thickness of the outer envelopes as seen obliquely is greatest. Thus *increased* radiation and *decreased* contrast of brightness will go hand in hand for variations due to changes in the transparency of the solar envelopes.

Since the sun is the support of the earth's temperature, and the cause of the circulation of the atmosphere, as well as the disturber of terrestrial magnetism, it is to be expected that variations in the solar activity would be associated with terrestrial changes. This has been found to be the case. For many years the close correspondence between sunspot activity and terrestrial magnetism has been known.

More recently Dr. Bauer has found a correlation between the short irregular fluctuations of solar radiation observed by the Smithsonian Astrophysical Observatory and certain outstanding changes of terrestrial magnetism. Various meteorologists, especially W. Köppen, have shown by their investigations that the temperature of the earth fluctuates with sunspot activity and is on the whole higher at sunspot minimum than at sunspot maximum. Helland-Hansen and Nansen draw attention to the fact that fluctuations in terrestrial temperature seem to have more frequent periodicity than fluctuations in sunspot activity. They draw attention also to the corresponding phenomenon in solar prominences and incline to think that the activity of the sun has a period of the order of three years which is reflected in the terrestrial temperatures.

Recently Dr. H. H. Clayton has determined the correlation between the short-period variations of the solar radiation as measured by the Smithsonian Institution at Mount Wilson, and the temperatures of some 50 stations distributed over the world. He finds some indications of correlation between the two variables, and that positive correlations generally occur in tropical regions, negative ones in temperate regions, and positive ones again in polar regions. At some stations the correlation is very strong, at others very weak. Dr. Nansen has studied these correlations for the Scandinavian Peninsula, and informs me privately that there is a fairly close and large factor of correlation there. He, however, is of the opinion that when sufficient data are correlated it will be found that areas of positive and negative correlation between short period solar changes and terrestrial temperatures will be associated with the great action centers of the atmosphere, rather than zonally, as supposed by Clayton.

In all investigations of the dependence of terrestrial temperatures on solar activity, it is apt to be found that the values go along together with a certain kind of dependence for a long course of years and then shift about and either show no dependence or else an opposite relation to what prevailed before. This is very confusing in statistical investigations of the kind, and has left so accomplished an investigator as Newcomb with a view that there is no variation of the sun, and no fluctuation of the earth's temperature dependent upon it except the slight one associated with the sunspot period.

The reason for this puzzling phenomenon of secular change of sign in temperature correlations may be that since the atmosphere absorbs a large portion of the sun's radiation, and since the capacity for heat of the atmosphere is very small, and since the configuration of the earth with its oceans, its mountains, its deserts, and the like, makes the relations between solar heat and terrestrial temperature very complex, a fluctuation of the solar radiation may easily cause a change in the distribution of atmospheric circulation, and thus a change in the direction of the wind prevailing at any given station. It is a matter of common observation that when we have southerly winds we generally have warm temperatures, and when northerly winds cold temperatures. If then a change in position of the great action centers of atmosphere presents a period of warm winds from the south, where cold ones from the north formerly prevailed, there will be corresponding general increase in the temperature of such a region, and this may happen notwithstanding that at the same time a decrease in the solar radiation has occurred which, while it primarily would tend to diminish temperatures secondarily, acts more powerfully in the contrary sense.

It is obviously essential to the proper study of these perplexing and important phenomena that sufficiently accurate measurements of the solar radiation should be available to follow the changes of solar output daily for a long course of years. When such a series of observations is available the dependence of terrestrial temperatures upon solar changes will probably be capable of elucidation. Hitherto the measurements made by the Smithsonian Institution at Washington, Mount Wilson, Mount Whitney, Bassour, Algeria, and Hump Mountain, N. C., have been too fragmentary, owing to cloudiness and other conditions, to give a satisfactory basis for such a study. About a year ago, however, the Institution sent an expedition to Calama, Chile, for the purpose of measuring the solar constant of radiation day after day for a term of years. The station lies at the eastern edge of the nitrate desert, about 150 miles northeast of Antofagasta, on the River Loa and on the railroad leading from Antofagasta to Bolivia. The expedition is in charge of Mr. A. F. Moore, director, with Mr. L. H. Abbot, assistant.

The location chosen at Calama is an abandoned mining property of the Chile Exploration Co., which they very generously put at our disposal for this purpose. The expedition took station in June, 1918, and began observing regularly on July 27, 1918. On last accounts, January 12, 1919, the solar constant of radiation had been observed on 123 days out of a possible 170 days. In the month of December an unusually large number of days was lost on account of cloudiness, and it is not improbable that similar conditions may prevail in January and February, when the rainy season occurs in Bolivia. Unpublished meteorological observations kindly furnished by Dr. Walter Knoche, formerly director of the meteorological service of Chile, indicated a somewhat larger proportion of favorable days than has been found, but we incline to the view that the present period is disturbed from the normal all over the world, and that perhaps in the course of a year or two better conditions may be found.

The values of solar radiation thus far observed have been generally high, practically every one above 1.90, and they average above 1.95 calories per square centimeter per minute. This would perhaps be expected in view of the large number of sunspots still prevailing, although we have passed the maximum of the present sunspot period.

A few words in regard to the kind of apparatus employed may be of interest. Outside the observing shelter is a coelostet of two mirrors with clockwork rotating the polar axis, on which one of the mirrors rests at the rate of one revolution in 48 hours. The second mirror sends the solar beam horizontally southward into the observing shelter, where it falls upon a vertical slit about 8 cm. high and 0.4 mm. wide. The light from the slit passes on about 3 m. to a 60° prism of ultra-violet crown glass, which prism is traversed by the rays in minimum deviation, and the emergent beam is reflected by a plane mirror, which lies parallel with the back of the prism onwards toward a concave image-forming mirror about 1 m. farther to the south. This mirror focuses the spectrum upon the sensitive strip of a vacuum bolometer at about 1 m. distant from it.

The vacuum bolometer, designed for the highest possible sensitivity, is entirely inclosed within a sealed glass vessel which is inclosed in a suitable case of metal having a diaphragmed vestibule for the entrance of the spectrum, and an eyepiece to observe the focus upon the bolometer strip. The warming and cooling of the exposed strip of the bolometer is detected by means of a highly sensitive Thomson reflecting galvanometer, which measures the amount of unbalancement in the Wheatstone's bridge, of which the bolometer strips are a part, due to the differential rise of temperature of the exposed bolometer strip over its neighbor, which is hidden from the spectrum by a diaghragm. Changes of the temperature of the exposed bolometer strip as small as one one-millionth of a degree Centigrade are recognizable upon the scale of the galvanometer, and are autographically reproduced on a photographic plate which moves vertically in front of the galvanometer in a box behind a horizontal slit.

The movement of the photographic plate is governed by clockwork, and the same clockwork moves the spectrum along over the exposed strip of the bolometer. Thus the horizontal deflections of the galvanometer are drawn out upon the photographic plate into a sinuous line, whose high peaks represent warm parts of the spectrum and whose low valleys represent cool parts of the spectrum.[1] The whole length of the solar spectrum from 0.34 microns to 2.8 microns is autographically reproduced as an energy curve in about seven minutes by this apparatus.

In order to prevent the curve from going off of the photographic plate at the most intense regions of the spectrum, we employ a series of three rotating sectors which may be introduced before the slit of the spectroscope and which cut down the intensity in the proportions one-third, one-ninth, and one-thirtieth, approximately.

Six such spectro-bolometric energy curves of the solar spectrum are made on each observing day between the hours when the sun is low and the sun is high.

The range of air masses corresponding to the measurements is usually taken from about 5 to about 1.2 times that which would prevail if the sun were vertically overhead. This requires a time interval of approximately three hours for the observations, and it is an unsatisfactory feature of the method that so long a time must elapse in order to determine the transparency of the atmosphere. For it is possible for the approach of changes in meteorological conditions in the upper atmosphere to produce a gradual clearing or increasing turbidity of the air, and these tend to produce too high or too low values of the solar constant of radiation, respectively. We are attempting to develop instantaneous methods for estimating atmospheric transparency. If successful they will largely increase the number of satisfactory determinations.

As the bolometer is not in itself a standard instrument, we are obliged to determine the scale of intensities which it represents. In order to do this, we note that the area included under the spectro-bolometric curve, when the

[1] See this REVIEW, May, 1902, Plate 1, XXX-50, for reproductions of bolograms.—ED.

curve has been corrected for losses in the apparatus, must be proportional to the total heating effect of all the sun's rays combined, as these might be observed with the pyrheliometer. Accordingly, in standardizing the bolometric work we read the pyrheliometer at the time when each of the six curves is made, and by dividing the reading of the pyrheliometer by the area of the corresponding bolographic curve a constant is obtained from which the sensitiveness of the bolometer is determined. This constant is applicable not only to the curves as they actually stand at the earth's surface, but also to the curve outside the atmosphere as corrected for atmospheric transmission, as the latter is determined by the dependence of the intensities at different wave lengths on the thickness of the atmosphere traversed.

We employ to measure the total heat of the sun the standardized silver disk pyrheliometer, of which the institution has furnished about 30 copies to various governmental and private institutions in different parts of the world. Two copies of this instrument are employed at Calama. They are mounted upon the same equatorial stand, and the observer reads them successively, so that during the taking of each spectro-bolometric curve he gets the reading of the two pyrheliometers.

The air mass corresponding to the observation is determined by means of a theodolite which gives the zenith distance of the sun. A table has been prepared giving the air mass corrected according to Bemporad, corresponding to the zenith distance observed. This procedure saves the determinations of time and the computation of the air mass in the manner still employed at Mount Wilson.

In reducing the observations of the spectro-bolometer, we measure the heights of the six successive curves at about 40 points, corresponding to the different wave lengths in the spectrum. The determination of the corresponding intensities in the solar spectrum outside the atmosphere we determine by a graphical method instead of the logarithmic computations which we have hitherto used in Washington.

For the purpose of this graphical extrapolation we have constructed a special slide-rule machine. An accurate steel frame with a horizontal scale of distances in centimeters has upon it six slide rules whose positions may be adjusted along the horizontal scale according to the air mass at which observations were made. We then set off upon the sliders vertically the observed intensities of solar radiations at a single wave length as read from the six curves. As these values are logarithmically plotted in the slide rule they fall upon a straight line, which produced to the abscissa of zero air mass gives the intensity which would be found outside the atmosphere, as on the moon for example. The numerical value is read off on a seventh slide rule situated at the zero of air mass.

In order to make extrapolation easier, a taut wire attached to the slider of the rule located at zero air mass and to a slidable reel at the other extremity of the steel frame is adjusted until it falls as closely as possible upon the six points determined by the six slide rules. In this way quick and accurate extrapolations of the data to the zero of air mass may be made.

The observers are so skillful and zealous in the reduction of the observations that, thanks also to these special devices, they are able to complete the determination of the solar constant of radiation on the same day that the observations are made, although in our former practice at Washington the computation required amounted to 25 hours. Thus it is possible for two observers to determine in a single day the solar constant of radiation so as to be in a position to telegraph the result, if it was desirable, within 10 hours of the beginning of the observations. However, so grinding an occupation as the observation and computation of solar constant values day after day would soon wear out so small a staff, and we expect in the immediate future to add another person to it.

Messrs. Moore and Abbot are in communication with Dr. H. H. Clayton, of the meterological service of Argentina, who is making studies of the relations of temperature of Argentina to the solar constant values they determine. Dr. Clayton speaks very enthusiastically of the apparent connection of the two variables and even mentions that correlations as high as 68 per cent are being found between them.

If this state of affairs should be confirmed, if it is found in future that the temperature of any station upon the earth's surface may be predicted for some time in advance on the basis of the values of the solar constant of radiation, it will seem to be indicated that a sufficient number of solar radiation stations should be established to observe not merely 70 per cent of the days, but all days, for the use of meteorologists. For such a purpose three or four more stations ought to be equipped in the most widely separated cloudless regions of the earth—let us say Australia, South Africa, India, and Egypt. While it would no doubt be advantageous if all these stations could be under a single management, as, for instance, that of the Smithsonian Institution, yet the institution has not at present the means available for the establishment and continuation of them. About $50,000 for the establishment and $50,000 annually for maintenance would be needed. Very probably it might be easier to secure the necessary funds if the various governments of the regions indicated should themselves establish and support their observing stations. Possibly no defect of homogeneousness in the results would arise from such a divided control. At all events the matter of the establishment of additional stations may well be delayed for at least a year, until the results of Dr. Clayton on the correlation of solar radiation with terrestrial temperatures shall be further advanced.

TERRESTRIAL WEATHER AND SOLAR ACTIVITIES.

By CHARLES F. MARVIN, Chief of Weather Bureau.

[Dated: Washington, Feb. 21, 1919.]

Meteorologists have long been accustomed to ascribe practically all atmospheric motions, both local and general, to the gravitational flow resulting from the local and general contrasts of temperature over the surface of the earth. The atmosphere derives its heat, not directly from the sun, except to a small extent, but chiefly from the surface of the earth itself. The daily sequence of sunshine and darkness; the varied distribution of clear and cloudy skies; diversities of surface cover added to contrasts of land and water areas, including the phenomena of evaporation, condensation, and precipitation; the cycle of the seasons, and above all the fluctuating but nevertheless perpetual contrasts of surface temperatures, ranging all the way from the heat of the Tropics to the intense cold of the polar zones constitute a complex series of varied and changeable influences seemingly abundantly adequate to cause and explain every feature of our weather conditions, however changeable we may find them.

These differences and contrasts on the one hand perpetually disturb the orderly arrangement of air densities